FURTHER RESULTS FOR NON-GIMBALED ANTENNA POINTING

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SECTION 1 - INTRODUCTION

This report details the simulations run at New Mexico State University to simulate the interactions between zenith-pointing antenna on a spin-stabilized satellite and the Tracking and Data Relay Satellites (TDRS) in the Space Network (SN) operated by the National Aeronautics and Space Administration (NASA). Preliminary results for this study have been reported in [1], [2], and [3]. This report extends the preliminary study in the following ways:

- 1. The simulation period was extended from the previous maximum of 10 days to 30 days
- 2. The number of TDRS satellites in the SN constellation was enlarged to three to allow for the current TDRS positioned to close the Zone of Exclusion over the Indian Ocean
- 3. The simulation methodology was improved by using the commercial orbital analysis program Satellite Tool Kit.

The following sections describe the simulation environment used, the exact cases studied, the results of the simulations, and, finally, the conclusions and further work for this project.

SECTION 2 - SIMULATION ENVIRONMENT

The initial investigations [1], [2] and [3] were developed primarily using MATHCAD and Visual Basic programming environments to perform the necessary computer work. In this study, the simulation environment has been upgraded to use the commercial software product Satellite Tool Kit (STK) version 3.0 [4]. This has several advantages over the hand-coded original analysis, including perturbation models for propagating the orbital elements (STK uses the MSGP4 propagation model for all of the simulations used here) and the ability to choose the attitude control system model for the satellites. Because of the more exact mathematical model, the simulation duration was extended to 30 days over the original 1-10 day simulations reported earlier.

The STK program was run on a standard PC-compatible computer (133 MHz clock speed, 16 MB memory) running Windows 95.

SECTION 3 - CASES STUDIED

STK was configured for a constellation of three TDRS spacecraft with the orbital elements given

in Table 1. The TDRS orbital elements were taken from [5]. The TDRS constellation was configured for both the nominal TDRS east (TDRS-E) and west (TDRS-W) spacecraft plus the third TDRS positioned to close the Zone of Exclusion (ZOE) over the Indian Ocean. The attitude control model for all three TDRS was set to the default of nadir alignment with ECF velocity constraint. The spinning satellite was configured in STK with the elements shown in Table 2. The attitude control model was that of a nadir-pointing, spinning satellite. An example plot showing the TDRS locations and a sample of the spinning satellite orbits over a 24-hour period is given in Figure 1.

A contact between a given TDRS and the spinning satellite occurs when the antenna model on the TDRS is visible to the antenna model on the spinning satellite as illustrated in Figure 2. At position #1 of Figure 2, the two antennas are not mutually visible while at position #2 of Figure 2, they are. The STK program tracks the time of these contacts automatically and produces a report listing them over the simulated 30-day duration. The antenna model used on the TDRS is emulating the Multiple Access antenna system. In STK, antennas are modeled as sensor objects (a generic term used for any sensor, antenna, or object on a spacecraft that STK needs to keep track of). Associated with each sensor object is its visibility. In STK, this is called its cone angle and it represents the half-angle of the cone containing the full response of the sensor. For an antenna, this total cone angle would correspond to the Half Power Beam Width (HPBW), as shown in Figure 3. The cone angle used in STK would then be one-half of the HPBW.

SECTION 4 - RESULTS

The access of the satellite was simulated over the following sets of conditions:

- a. Orbital altitude covering 600 km through 1200 km
- b. Orbital inclination angle covering 20° through 100°
- c. Antenna cone angle of 10° through 40° corresponding to effective beamwidths of 20° through 80° .

In each of the simulations, we look at the access to each of the TDRS satellites in the SN constellation. We examine the following statistics as a function of orbital altitude, orbital inclination angle, and antenna cone angle:

Table 1. Orbital F	Elements for the TDRS	Spacecraft Used in the	STK Simulations
element	TDRS-E	TDRS-W	TDRS-ZOE
epoch	96309.07963542	96309.52072197	96310.80322976
MM (rev/day)	1.00269234	1.00270108	1.00269000
eccentricity	0.00088320	0.00040560	0.00057810
inclination (degrees)	0.1690	0.0743	2.7767
ω_p (degrees)	119.7426	173.4374	153.3718
RAAN (degrees)	90.1551	80.9672	71.2162
MA (degrees)	181.4839	162.7795	195.2850

Table 2. Orbital Electric STK Simulations	ments Used for the Spinning Satellite in the
element	value
MM (rev/day)	13.16 through 14.89
Altitude (km)	600 through 1200
eccentricity	0
inclination (degrees)	20° through 100°
ω_{p}	0
RAAN (degrees)	0
MA (degrees)	0

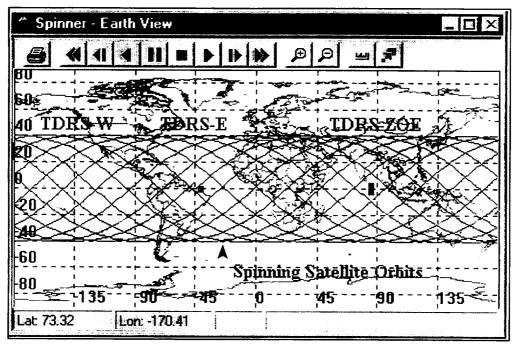


Figure 1 - Example orbital ground tracks for the three TDRS satellites and the spinning satellite over a 24-hour period using STK to perform the simulation.

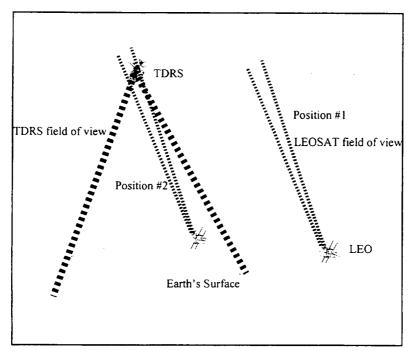


Figure 2 - TDRS/LEO Satellite Access Geometry.

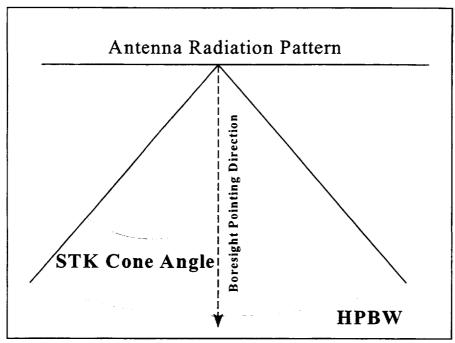


Figure 3 - Relationship between STK antenna cone Angle and antenna HPBW

- a. minimum, maximum, and average contact length in minutes
- b. total daily contact duration for each TDRS and the SN constellation
- c. average number of contacts per day for each TDRS
- d. average contact duration

Tables 3 through 6 summarize the results obtained when the simulations covered a 30-day period. Figures 4 and 5 plot the results for TDRS West illustrating the average number of contacts per day and the average contact duration. The TDRS East and ZOE satellites have very similar results so only TDRS West is shown. Figure 6 illustrates the total SN constellation average daily contact time.

				_	_	_					_						
-			INCLINATION														
			20°			40°			°09			.08	\neg	1	100°	_	
Half Angle 10°	10°		TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	뒧	TDRS-ZOE	TDRS-E	뒭	TORS-ZOE
_	30-day	Min (sec)	20.07	38.10	31.33	93.81	25.84	35.22	86.91	50.89	42.07	38.43	34.09	69 39	49.59	55.01	53.20
		Max (sec)	286.96	287.00	287.06	283.43	283.34	351.36	278.04	278.00	278.95	271.89	271.88	272.64	265.56	265.60	265.34
		Mean (sec)	224.81	228.15	222.28	224.80	221.10	224.86	225.61	220.93	220.47	212.01	216.44	217 22	206.25	211.65	206.75
		Total Duration(sec)	26078.05	26237.61	25117.14	13712.94	13929.16	13716.53	10152.40	10162.84	10361.97	8692.19	9090.54	9123.31	9074.87	8254.45	8890 24
		Total Duration (min)	434.63	437.29	418.62	228.55	232.15	228.61	169 21	169.38	172.70	144.87	151.51	152.06	151.25	137.57	148.17
	Avg. Dally	y Contact Time (sec)	869.27	874.59	837.24	457.10	464.31	457.22	338.41	338.76	345.40	289.74	303.02	304.11	302.50	275.15	296.34
		_	14.49	14.58	13.95	7.62	7.74	7.62	5.64	5.65	5.76	4.83	5.05	5.07	5.04	4 59	4.94
		Number of Contacts	3.87	3.83	3.77	2.03	2.10	2.03	1.50	1.53	1.57	1.37	1.40	1.40	1.47	1.30	1.43
	Ava.	Contact Duration (sec)		228.15	222.28	224.80	221.10	224.86	225.61	220.93	220.47	212.00	216.44	217.22	206.25	211.65	206.75
	_	Contact Duration (min)	L	3.80	3.70	3.75	3.69	3.75	3.76	3.68	3.67	3.53	3.61	3.62	3.44	3.53	3.45
		Constellation Contact	L	43.03			22.95			17.04			14.96			14.57	
Ī	20° 30-day	Min (sec)	10.87	19.82	23.82	112.41	86.16	4.82	19.00	98.99	15.60	51.88	55.46	113.55	28.58	116.37	40.81
		_	575.64	575.68	575.99	568.57	568.49	573.95	557.90	H	559.53	545.56	545.43	547.03	532.75	532.83	532.60
		Mean (sec)	434.07	434.36	433.63	445.31	447.72	448.57	439.57	439.49	439.13	426.67	433.69	437.33	422.32	419.19	413.04
		Total Duration(sec)	115463.12	115975.23	٦	56109.29	56412.57	56519.89	40879.78	3 41312.38	42156.43	36693.25	35562.81	35861.38	35897.12	36469.79	35934.04
		Total Duration (min)	1924.39	1932.92		935.15	940.21	942.00	681.33	688.54	702.61	611.55	592.71	597.69	598.29	607.83	598.90
									+	\dashv							
	Avg. Dally	y Contact Time (sec)	3848.77	3865.84	3714.75	1870.31	1880.42	1884.00	1362.66	7	1405.21	1223.11	1185.43	1195.38	1196.57	1215.66	1197.80
		Contact Time (min)	64.15	64.43	61.91	31.17	31.34	31.40	22.71	22.95	23.42	20.39	19.76	19.92	19.94	20.26	19.96
		Number of Contacts	8.87	8.90	8.57	4.20	4.20	4.20	3.10	3 13	3.20	2.87	2.73	2.73	2.83	2.90	2.90
	Avg	Contact Duration (sec)	434.07	434.36	433.63	445.31	447.72	448.57	439.57	439.49	439.13	426.67	433.69	437.33	422.32	419.19	413.04
		Contact Duration (min)	7.23	7.24	7.23	7.42	7.46	7.48	7.33	7.32	7.32	7.11	7.23	7.29	7.04	6.99	6.88
		Constellation Contact		190.54			93.91			90.69			60.04			60.14	
	30° 30-day	Min (sec)	538.60	542.17	390.31	80.61	35.34	94.54	93.29	97 78	142.02	102.53	137.54	42.36	126.70	150.81	75.37
		Max (sec)	867.65	867.68	868.25	857.01	856.89	858.70	841.05	840.86	843.44	822.34	822.14	824.57	803.03	803.13	802.97
		Mean (sec)	719.76	720.98	699.33	665.38	671.80	670.88	662.21	666.18	669.54	654.77	649.26	648.35	632.63	638.95	631.55
		Total Duration(sec)	300859.20	300649.79	291618.91	132116.02	131672.37	131491.62	94033.67	7 94597.88	96413.58	83155.39	81806.27	82339.84	82242.30	82424.27	82101.57
		Total Duration (min)	5014.32	5010.83	4860.32	2201.93	2194.54	2191 53	1567.23	1576.63	1606.89	1385.92	1363.44	1372.33	1370.71	1373.74	1368.36
									-	\dashv							
	Avg. Daily	ly Contact time (sec)	10028.64	10021.66	9720.63	4403.87	4389.08	4383.05	3134.46	3153.26	3213 79	2771.85	2726.88	2744.66	2741.41	2747.48	2736.72
			167.14	167.03	162.01	73.40	73.15	73.05	52.24	52.55	53 56	46.20	45.45	45.74	45.69	45.79	45.61
		Number of Contacts	13.93	13.90	13.90	6.60	6.53	6.53	473	4.73	4 80	4 23	4 20	4.23	4 33	4.30	4.33
	Avg.	Contact Duration (sec)	719.76	720.98	699.33	667.25	671 80	670.88	662.21	666.18	669.54	654.77	649.26	648.35	632.63	638.95	631.55
		Contact Duration (min)	12.00	12.02	11.66	11.12	11.20	11.18	11.04	11.10	11.16	10 91	10.82	10.81	10 54	10.65	10.53
		Constellation Contact	Ц	496.14			219.53			158 28			137 32			137.02	
									-						_		
	40° 30-dav	Min (sec)	872.56	967.12	896.56	63.80	62.52	43.64	59.49	144.95	16.69	54 25	148 31	114 84	84 88	176.30	103.91

	Max (sec)	1164.55	1164.55 1164.56 1165.54	1165.54	1150.31	1150.19	1152.56	1128 96	1128 75	1132 12	1103.91	1103.67	1106.88	1077.96	1078.10	1078.04
	Mean (sec)	1071 10	1072.27 1060.79	1060.79	887.28	95.068	893.01	896.48	901.25	895.82	878.50	884.26	879 24	858.52	861 41	853.30
	Total Duration(sec) 447718.61 447137.56 442350.33	44771861	447137.56	442350.33	251099.91	251138.43 251851.27	251851.27	172123 91	173039.83	176477 16	150222.62	149440.02	150349.39	149382 79	148162 56	149327 01
	Total Duration (min)	7461.98	7452.29 7372.51	7372.51	4185.00	4185.64	4197.52	2868.73	2884.00	2941.29	2503.71	2490.67	2505.82	2489.71	2469.38	2488.78
Avg. Daily	Avg. Daily Contact Time (sec) 14923.95 14904.59 14745.01	14923.95	14904.59	14745.01	8370.00	8371.28	8395.04	5737.46	5767.99	5882.57	5007.42	4981.33	501165	4979 43	4938.75	4977 57
	Contact Time (min) 248 73	248 73	248.41	245.75	139.50	139.52	139.92	95.62	96.13	98.04	83.46	83.02	83.53	82.99	82.31	96.28
	Number of Contacts	13 93	13.90	13.90	9.43	9.40	9.40	6.40	6.40	6.57	5 70	5.63	5.70	5.80	5 73	5.83
 Av9.	Avg. Contact Duration (sec) 1071.10	1071 10	1072.27	1060 79	887.28	990.56	893.09	896.48	901.25	895.82	878.49	884.26	879.24	858 52	861.41	853.30
	Contact Duration (min) 17.85		17.87	17.68	14.79	14.84	14.88	14.94	15.02	14 93	14.64	14.74	14.65	14.31	14.36	14.22
	Constellation Contact		742.83			418.89			289.85			249.96			248.17	

Marchange 10 Marchael																		
10 10 10 10 10 10 10 10							-								1			
10- 10-5	-			INCLINATION			١		1	3			8			100		
30-day Mint (sec) 2405 2820 1314 2217 1169 4323 1516 1516 14223 1516 1516 14223 1516	If Angle 10°			TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	_	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE
Ang. Delly Contact Time (sec) 296 57 298 57 298 57 298 57 298 67 298 67 298 67 298 67 298 67 298 67 298 57 257 63 227 63 227 63 227 63 227 63 227 63 227 63 227 63 227 73 227 77 Avg. Dally Contact Time (sec) 870 09 873 74 439.77 420.88 227 63 227 63 227 73 227 77 Avg. Dally Contact Time (min) 1450 14.66 140.2 7.59 420 1.70 7.59 Avg. Dally Contact Time (min) 3.85 3.86 3.77 3.89 3.77 3.89 3.70 2.00 1.83 2.00 1.83 2.00 1.83 3.85 3.80 3		30-day	Min (sec)	24.05	28.20	13.14	22.17	1	43.23	172.87	69.84	50.55	62.45	₩	33.82	86.08) 	78.04
Avg. Contact Time (sec) 231 00 231 46 223.32 227.53 229.51 227.77 Avg. Dally Contact Time (sec) 870 09 679.54 841.17 455.76 1321.86 127.77 Avg. Dally Contact Time (sec) 870 09 679.54 841.17 455.26 443.73 455.53 Avg. Contact Duration (sec) 370 0 273.46 220.32 220.63 220.77 759 Avg. Contact Duration (sec) 231.00 231.46 223.32 220.63 220.77 759 Avg. Contact Duration (sec) 231.00 231.46 223.32 220.53 220.53 220.77 Avg. Contact Duration (sec) 231.00 231.46 223.32 220.53 3.80 3.80 Avg. Contact Duration (sec) 231.00 231.46 223.32 220.53 3.80 3.80 Avg. Dally Avg. Dally 220.83 3.80 3.77 3.79 3.80 3.80 Avg. Dally Avg. Dally 220.83 3.80 3.81 3.80 3.81			Max (sec)	298.57	298.57	298.90	294.66	294.63	295.18	287.04	288.88	289.76	281.91	282.17	329.96	275.38	274.56	275.15
Avg. Daily Contact Time (sec) 26192 59 26294 59 126574 56 13311 80 1365 11 1365 17 Avg. Daily Contact Time (sec) 870 39 879 34 430.78 227 63 227 77 Avg. Daily Contact Time (min) 14 50 14 66 14 02 759 740 7.59 Avg. Contact Time (min) 14 50 14 66 14 02 759 740 7.59 Avg. Contact Time (min) 385 3.86 3.77 2.27 63 2.27 63 3.80 Contact Duration (exc) 231 00 231 46 232 32 2.27 63 3.72 3.79 3.89 3.80 Avg. Contact Time (min) 3.85 3.86 3.72 3.72 3.72 3.70 2.27 6 Avg. Daily Min (sec) 2.27 5 3.06 0 38.12 3.80 3.80 3.80 3.80 3.80 3.80 3.80 3.80 3.80 3.80 3.80 3.80 3.80 3.80 3.80 3.80 3.80 3.80			Mean (sec)	231.00	231.46	223.32	227.63	229.51	227.77	242.58	226.29	222.07	216.81	227.94	220.93	223.74	204.09	223.74
Ayg. Dally Contact Time (min) 435 O4 439.77 420.58 227 63 227 63 227 77 Ayg. Dally Contact Time (min) 14.50 14.66 14.02 7.59 7.40 7.59 Avg. Contact Time (min) 14.50 14.66 14.02 7.59 7.40 7.59 Avg. Contact Duration (lasc) 37.7 38.0 37.7 2.00 19.3 2.00 Avg. Contact Duration (lasc) 221.66 22.32 22.00 19.3 2.00 Avg. Contact Duration (min) 3.85 39.63 37.7 2.00 19.3 2.00 Avg. Contact Duration (min) 3.85 5.96 5.98 5.98 5.98 7.0 37.7 2.26 4.85.7 2.26 Avg. Dally Contact Time (min) 1.905.45 1.94.89 5.99.70 5.91.6 5.91.7 7.8 7.8 7.8 7.8 7.8 7.8 7.8 7.8 7.8 7.8 7.8 7.8			Total Duration(sec)	26102.59	26386.28	25234.95	13657.76	_	13665.91	9945.73	10182.82	10215.26	8889.12	8889.49	8837.22	8726.03	8979.73	8949.39
Avg. Dally Contact Time (sec) 870.09 879.54 841.17 455.26 443.73 455.35 Avg. Contact Duration (sec) 231.00 145.00 146.6 140.0 75.9 740.7 75.9 Avg. Contact Duration (min) 3.85 3.77 2.00 1.93 2.00 Avg. Contact Duration (min) 3.85 3.86 3.72 2.00 1.93 2.00 30-day Minnber of Contact Duration (min) 3.85 3.86 3.72 2.00 1.93 2.07 30-day Minnber of Contact Duration (min) 3.85 3.86 3.72 3.79 2.25.66 48.49 Avg. Dally Contact Duration (min) 3.85 3.86 3.97 3.73 3.73 3.83 3.80 Avg. Dally Contact Duration (min) 1.905.45 1.914.86 1.99.77 4.80.80 3.82.97 3.81 3.83 4.07 Avg. Dally Contact Duration (min) 7.59 7.57 7.45 7.81 7.81			Total Duration (min)	435.04	439.77	420.58	227.63	221.86	227.77	165.76	169.71	170.25	148.15	148.16	147.29	145.43	149.66	149.16
Avg. Dally Contact Time (see) 870.09 879.54 841.17 455.26 44373 455.35 Avg. Contact Time (see) 14.50 14.66 14.02 7.59 740 7.59 Avg. Contact Imme (min) 14.50 14.66 14.02 7.59 740 7.59 Avg. Contact Duration (sec) 22.16 221.00 231.46 223.32 22.00 1.59 Contact Duration (sec) 22.75 30.60 38.12 37.9 3.83 3.80 30-day Min (sec) 22.75 30.60 38.12 1.25.68 48.40 Avg. Dall (sec) 45.41 447.11 46.86 46.84 46.42 Avg. Dally Contact Time (sec) 3810.89 3829.70 581.18 58.46 46.85 Avg. Dally Contact Time (sec) 3810.89 3829.70 3.81 8.83 4.84 Avg. Dally Contact Time (sec) 3810.89 3829.70 3.81 3.82 1.82																		
Avg. Daily Contact Time (min) 14.50 14.66 14.02 7.59 7.40 7.59 Avg. Contact Duration (contact) 3.77 3.80 3.77 2.00 1.93 2.00 Avg. Contact Duration (contact) 2.31 or 3.86 3.77 3.80 3.77 3.79 3.83 3.80 Contact Duration (min) 3.65 3.86 3.72 3.79 3.83 3.80 30-day Min (asc) 2.25 3.00 3.81 3.82 3.79 3.83 3.80 30-day Min (asc) 5.89.96 5.98.98 5.98.70 5.91.16 5.91.5 5.256 Avg. Dally Contact Duration (asc) 1.435.49 454.12 447.11 486.60 466.84 460.52 Avg. Dally Contact Time (min) 1.905.46 1144.86 1892.77 929.88 9.18.70 9.18.70 Avg. Dally Contact Duration (asc) 3.54 4.54.12 447.11 486.60 466.94 460.52 Avg. Dally Min (asc)		Avg. Daily	\Box	870.09	879.54	841.17	455.26	443.73	455.53	331.52	339.43	340.51	296.30	296.32	294.57	290.87	299.32	298.31
Avg. Contact Duration (sec) 377 360 377 2.00 133 2.00 Avg. Contact Duration (min) 3.85 3.72 3.72 3.29 51 2.27 77 Contact Duration (min) 3.85 3.72 3.72 3.83 3.80 3.0-day Min (sec) 22.75 3.06.0 36.16 59.16 59.16 59.16 59.16 59.16 59.16 59.16 46.27 22.56 46.84 46.87 46.87 46.82 46.				14.50	14.66	14.02	7.59	7.40	7.59	5.53	5.66	5.68	4.94	4.94	4.91	4.85	4.99	4.97
Avg. Contact Duration (sec) 231 00 231.46 223.32 227.63 229.51 227.77 Contact Duration (min) 3.85 3.86 3.72 3.79 3.83 3.80 30-day Contact Duration (min) 3.85 3.86 3.72 3.83 3.80 30-day Min (sec) 22.75 3.060 36.12 135.38 11.266 48.49 Mean (sec) 589.96 599.98 589.70 591.16 591.12 592.46 Avg. Dally Min (sec) 14326.77 114891.71 113566.14 5576.29 969.84 460.52 Avg. Dally Contact Time (min) 1905.45 1914.88 1892.77 929.38 918.31 936.40 Avg. Contact Duration (sec) 3810.89 382.72 3765.54 188.76 188.77 3.93 187.79 Avg. Dally Contact Duration (sec) 385.8 454.12 447.11 468.60 468.91 460.52 Avg. Dally Contact Time (min) 7.59 7.45 474			Number of Contacts	3.77	3.80	3.77	2:00	1.93	2.00	1.37	1.50	1.53	1.37	1.30	1.33	1.30	1.47	1.33
Contact Duration (min) 3.85 3.86 3.72 3.79 3.83 3.80 30-dey Constellation Contact 43.21 43.21 1.55.88 1.26.6 48.49 30-dey Min (sec) 22.75 30.60 38.12 135.38 112.66 48.49 Mean (sec) 568.96 598.98 599.70 591.16 591.12 592.46 Mean (sec) 14326.77 114891.71 113568.14 55762.90 557.82 465.34 465.27 Avg. Delly Contact Time (min) 1905.45 191.486 1892.77 1929.38 918.31 358.40 Avg. Delly Contact Time (min) 63.51 63.83 63.09 30.88 30.61 31.71 358.40 Avg. Delly Contact Time (min) 7.59 454.12 47.11 468.60 466.94 460.52 Avg. Delly Contact Time (min) 7.59 7.45 47.11 468.60 466.94 460.52 Avg. Delly Contact Time (min) 7.54 <t< td=""><th></th><td></td><td>Contact Duration (sec)</td><td>Ш</td><td>231.46</td><td>223.32</td><td>227.63</td><td>229.51</td><td>227.77</td><td>242.58</td><td>226.28</td><td>222.07</td><td>216.81</td><td>227.94</td><td>220.93</td><td>223.74</td><td>204.08</td><td>223.73</td></t<>			Contact Duration (sec)	Ш	231.46	223.32	227.63	229.51	227.77	242.58	226.28	222.07	216.81	227.94	220.93	223.74	204.08	223.73
Society Anni (sec) 22.75 30.60 36.12 135.38 112.66 48.49 30-day Max (sec) 22.75 30.60 36.12 135.38 112.66 48.49 Amac (sec) 598.96 598.98 599.70 591.66 36.94 46.52 Mean (sec) 455.49 454.12 47.11 468.60 466.94 460.52 Avg. Dally Contact Duration (min) 1905.45 1914.86 1892.77 929.38 918.31 936.40 Avg. Dally Contact Time (min) 63.51 63.83 63.99 30.89 30.61 312.79 Avg. Contact Duration (min) 7.59 7.57 7.45 7.81 7.89 30.62 187.79 Avg. Contact Duration (min) 7.59 7.57 7.45 7.81 7.89 30.62 187.79 Avg. Dally Contact Duration (min) 7.59 7.57 7.45 7.81 7.89 1.89.70 Avg. Contact Duration (min) 7.86.20 56.874 36.57 <th></th> <td></td> <td>Contact Duration (min)</td> <td></td> <td>3.86</td> <td>3.72</td> <td>3.79</td> <td>3.83</td> <td>3.80</td> <td>4.04</td> <td>3.77</td> <td>3.70</td> <td>3.61</td> <td>3.80</td> <td>3.68</td> <td>3.73</td> <td>3.40</td> <td>3.73</td>			Contact Duration (min)		3.86	3.72	3.79	3.83	3.80	4.04	3.77	3.70	3.61	3.80	3.68	3.73	3.40	3.73
30-day Min (sec) 22.75 30.60 36.12 155.38 112.66 48.49 Max (sec) 588.96 598.18 599.70 581.16 591.12 522.46 Mann (sec) 455.49 455.412 447.11 468.60 466.91 450.46 Total Duration (min) 1905.45 114891.71 113566.14 5576.290 5508.84 56183.74 Avg. Dally Contact Time (min) 455.41 454.12 447.11 468.60 465.84 460.52 Avg. Dally Contact Time (min) 35.51 63.83 63.09 30.98 30.61 31.21 Avg. Dally Contact Duration (min) 7.59 7.57 7.45 7.81 7.79 Avg. Dally Contact Duration (min) 7.59 7.57 7.45 7.81 7.89 Avg. Dally Contact Duration (min) 7.59 7.87 7.81 7.89 7.81 Avg. Dally Contact Time (sec) 29855.44 396.51 394.22 387.23 31820.52			Constellation Contact		43.21			22.56			16.86			14.79			14.81	
30-day Min (sec) 22.75 30.60 36.12 553.86 589.76 581.16 591.12 582.46 Mean (sec) 568.96 569.76 581.16 591.12 582.46 589.76 581.16 591.12 582.46 582.46 Inclad Duralion(sec) 1435.47 144891.71 113566.14 55762.90 5508849 56183.74 582.46 56183.74 Avg. Daily Contact Time (min) 63.51 63.83 63.09 30.98 918.31 936.40 5818.71 30.81 918.31 936.40 5618.77 144891.71 14356.77 929.88 918.31 936.40 5618.77 929.88 918.31 936.40 5618.77 929.88 918.31 936.40 936.90																		
Max (sec) 598.96 598.70 591.16 591.12 582.46 Mean (sec) 455.49 454.12 447.11 468.60 466.94 460.52 Total Duration (min) 1905.45 191.86.14 5578.29 55098.48 56183.74 Avg. Dally Contact Time (sec) 3810.89 3829.72 3785.54 1858.76 1825.77 398.80 30.61 31.21 Avg. Contact Duration (min) 63.51 63.83 63.09 30.98 30.61 31.21 32.7 393.0 407 78 Avg. Contact Duration (min) 7.59 7.57 7.45 7.81 7.78 7.69 7.81 7.89 7.57 7.45 7.81 7.78 7.69 7.81 7.89 7.79 7.85 7.81 7.89 7.81 7.81 7.89 7.81 7.81 7.89 7.81 7.81 7.89 7.81 7.81 7.89 7.81 7.81 7.89 7.81 7.81 7.81 7.89 7.81 7.81	20°	30-day	Min (sec)	22.75	30.60	36.12	135.38	112.66	48.49	9.44	88.86	66.98	107.98	30.89	64.62	50.92	108.72	74.72
Avg. Daily Contact Duration (min) 455.49 454.12 447.11 468.60 466.94 460.52 Avg. Daily Total Duration (min) 14326.77 114891.71 113566.14 55762.90 55084.8 56183.74 Avg. Daily Contact Time (sec) 3810.89 3829.72 3785.54 1868.76 1836.62 1872.79 Avg. Daily Contact Time (sec) 455.49 454.12 447.11 468.60 466.94 460.52 Avg. Contact Duration (min) 7.59 7.57 7.45 7.81 7.78 7.68 Constellation Contact 556.80 559.74 396.51 94.22 88.28 139.7 Avg. Daily Min (sec) 556.80 559.74 396.51 94.22 88.28 139.7 Avg. Daily Min (sec) 556.80 559.74 396.51 94.22 88.28 139.7 Avg. Daily Constellation Contact 148.52 748.73 745.7 74.88 139.20 Avg. Daily Contact Time (min) <			Max (sec)	598.96	598.98	599.70	591.16	591.12	592.46	578.76	579.57	581.32	565.97	566.09	29.795	552.41	552.04	552.06
Avg. Daily Contact Time (sec) 114326.77 114891.71 113566.14 55762.90 55098.48 56183.74 Avg. Daily Contact Time (min) 1905.45 1914.86 1892.77 929.38 918.31 936.40 Avg. Daily Contact Time (min) 63.51 63.87 8.37 8.47 3.98 30.88 30.61 31.21 Avg. Contact Duration (min) 7.59 45.42 4.47.11 468.60 466.94 407.22 Avg. Contact Duration (min) 7.59 45.41 3.96.51 3.97 3.97 3.93 4.07 Avg. Contact Duration (min) 7.59 7.57 7.45 7.81 7.88 7.88 Avg. Daily Mean (sec) 566.80 559.74 396.51 94.22 88.28 13.97 Avg. Daily Mean (sec) 7.48.73 733.42 70.157 698.42 693.79 Avg. Daily Contact Time (min) 165.92 165.97 162.17 17.78 1397.01 Avg. Contact Time (min) 12.65 </td <th></th> <td></td> <td>Mean (sec)</td> <td>455.49</td> <td>454.12</td> <td>447.11</td> <td>468.60</td> <td>466.94</td> <td>460.52</td> <td>436.98</td> <td>457.07</td> <td>460.42</td> <td>443.24</td> <td>442.00</td> <td>445.07</td> <td>435.60</td> <td>437.32</td> <td>434.55</td>			Mean (sec)	455.49	454.12	447.11	468.60	466.94	460.52	436.98	457.07	460.42	443.24	442.00	445.07	435.60	437.32	434.55
Avg. Daily Contact Time (sec) 3810.845 1914.86 1892.77 929.38 918.31 936.40 Avg. Daily Contact Time (min) 63.51 63.83 63.09 30.98 30.61 31.21 Avg. Contact Duration (sec) 455.49 454.12 447.11 468.60 466.54 460.52 Avg. Contact Duration (min) 7.59 7.57 7.45 7.81 7.78 7.68 Avg. Contact Duration (min) 7.59 7.57 7.45 7.81 7.78 7.68 Avg. Contact Duration (min) 7.59 7.57 7.45 7.81 7.78 7.68 Avg. Daily Man (sec) 902.93 904.05 894.22 88.28 130.20 Avg. Daily Contact Duration (min) 4877.66 4874.02 2914.03 2174.86 2153.47 2197.01 Avg. Daily Contact Duration (min) 165.92 165.17 72.50 71.78 73.23 Avg. Contact Duration (min) 165.92 165.			Total Duration(sec)	114326.77	114891.71		55762.90	_	56183.74	40638.91	40679.11	40977.54	35902.24	35360.23	35605.71	35718.92	35422.55	35633.04
Avg. Daily Contact Time (sec) 3810.89 3829.72 3765.54 1858.76 1836.62 1872.79 Avg. Contact Diration (sec) 3810.89 3829.72 3765.54 1858.76 1872.79 Avg. Contact Duration (min) 7.59 7.57 7.45 7.81 7.78 7.68 Contact Duration (min) 7.59 7.57 7.45 7.81 7.78 7.68 Contact Duration (min) 7.59 7.57 7.45 7.81 7.78 7.68 Avg. Contact Duration (min) 7.59 7.57 7.45 7.81 7.78 7.68 Avg. Daily Contact Time (min) 497.66 559.74 396.51 94.22 88.28 13.97 Avg. Contact Time (min) 497.66 497.07 4865.01 2174.86 2153.47 2197.01 Avg. Contact Duration (min) 165.92 162.17 72.50 71.78 73.33 Avg. Contact Duration (min) 165.92 165.97 162.17 72.50 71.78 73.75 </td <th></th> <td></td> <td>Total Duration (min)</td> <td>1905.45</td> <td>1914.86</td> <td>1892.77</td> <td>929.38</td> <td>918.31</td> <td>936.40</td> <td>677.32</td> <td>677.99</td> <td>682.96</td> <td>598.37</td> <td>589.34</td> <td>593.43</td> <td>595.32</td> <td>590.38</td> <td>593.88</td>			Total Duration (min)	1905.45	1914.86	1892.77	929.38	918.31	936.40	677.32	677.99	682.96	598.37	589.34	593.43	595.32	590.38	593.88
Avg. Daily Contact Time (sec) 3810.89 3829.72 378.54 1856.76 1836.62 187.79 Avg. Contact Time (min) 63.51 63.83 63.09 30.98 30.61 31.21 Avg. Contact Duration (sec) 455.49 454.12 47.11 468.60 466.94 460.52 Contact Duration (min) 7.59 7.57 7.45 7.81 7.78 7.66 Contact Duration (min) 7.59 7.57 7.45 7.81 7.78 7.66 Contact Duration (min) 7.59 7.57 7.45 7.81 7.78 7.66 Max (sec) 902.93 902.96 904.05 891.23 891.21 893.26 Avg. Daily Max (sec) 902.83 902.86 904.05 891.23 891.21 893.26 Avg. Daily Contact Duration (min) 4977.66 499.05 4865.01 2174.86 2153.47 2197.01 Avg. Contact Time (min) 165.92 162.17 72.50 71.78 73.23	+																	
Avg. Daily Contact Time (min) 63.51 63.83 63.09 30.98 30.61 31.21 Avg. Contact Duration (sec) 455.49 454.12 447.11 468.60 466.94 460.52 Contact Duration (min) 7.59 7.57 7.45 7.81 7.78 7.68 30-day Min (sec) 556.80 559.74 396.51 94.22 88.28 1397 Avg. Daily Man (sec) 556.80 559.74 396.51 94.22 88.28 1397 Avg. Daily Contact Time (min) 487.766 497.07 4865.01 2174.86 2153.47 2197.01 Avg. Contact Time (min) 165.92 162.17 72.50 71.78 73.33 Avg. Contact Duration (min) 12.48 12.48 12.22 11.69 11.64 11.56 Avg. Daily Contact Duration (min) 12.48 12.22 11.69 11.64 11.56 Avg. Daily Contact Duration (min) 12.48 12.22 11.69 11.69 11.69<		Avg. Daily	Contact Time (sec)	3810.89	3829.72	3785.54	1858.76	1836.62	1872.79	1354.63	1355.97	1365.92	1196.74	1178.67	1186.86	1190.63	1180.75	1187.77
Avg. Contact Duration (sec) 8.37 8.43 8.47 3.97 3.97 4.07 Avg. Contact Duration (sec) 455.49 454.12 447.11 468.60 466.94 460.52 Contact Duration (min) 7.59 7.57 7.45 7.81 7.78 7.68 30-day Min (sec) 556.80 559.74 396.51 94.22 88.28 13.7 Avg. Dally Mann (sec) 556.80 559.74 396.51 94.22 88.28 13.97 Avg. Dally Mann (sec) 965.93 902.98 904.05 891.21 893.26 Avg. Dally Contact Time (min) 497.66 497.07 4865.01 2174.86 2153.47 2197.01 Avg. Contact Time (min) 165.92 165.97 162.17 72.50 71.78 73.23 Avg. Contact Duration (min) 12.48 12.48 12.22 11.69 11.64 11.56 Avg. Contact Duration (min) 12.48 12.22 11.69 11.69 11.69			Contact Time (min)	63.51	63.83	63.09	30.98	30.61	31.21	22.58	22.60	22.77	19.95	19.64	19.78	19.84	19.68	19.80
Avg. Contact Duration (sec) 455.49 454.12 447.11 468.60 466.94 460.52 Contact Duration (min) 7.59 7.57 7.45 7.81 7.78 7.68 30-day Min (sec) 556.80 559.74 396.51 94.22 88.28 13.87 30-day Min (sec) 556.80 559.74 396.51 94.22 88.28 13.87 Max (sec) 902.39 902.98 904.05 891.23 893.26 Mean (sec) 786.59 748.52 701.57 698.42 893.26 Avg. Dally Contact Time (min) 4977.66 497.07 4865.01 2174.86 2153.47 2197.01 Avg. Contact Time (min) 165.92 165.97 162.17 72.50 71.78 73.23 Avg. Contact Direction (min) 12.48 12.48 12.22 11.69 11.64 11.56 Avg. Contact Duration (sec) 748.52 748.73 701.57 698.42 693.79 Contact Duration (min)			Number of Contacts	8.37	8.43	8.47	3.97	3.93	4.07	3.10	2.97	2.97	2.70	2.67	2.67	2.73	2.70	2.73
Contact Duration (min) 7.59 7.57 7.45 7.81 7.78 7.68 30-day Min (sec) 556.80 559.74 396.51 94.22 88.28 13.87 30-day Min (sec) 556.80 559.74 396.51 94.22 88.28 13.87 Mex (sec) 902.93 902.93 904.05 891.23 891.21 893.26 Mean (sec) 748.52 748.73 733.42 701.57 698.79 698.79 Avg. Dally Contact Time (min) 4977.66 4879.07 4865.01 2174.86 2153.47 2197.01 Avg. Contact Time (min) 165.92 165.97 162.17 72.50 71.78 73.23 Avg. Contact Duration (min) 12.48 12.48 12.22 11.69 11.69 11.64 11.56 Contact Duration (min) 12.48 12.22 11.69 11.69 11.56 Contact Duration (min) 12.48 12.22 11.69 11.69 11.69 Contact Duration (min)			Contact Duration (sec)	_	454.12	447.11	468.60	466.94	460.52	436.98	457.07	460.42	443.24	442.00	445.07	435.60	437.32	434.55
Avg. Daily Contact Duration (min) 15.68 0 55.974 396.51 94.22 88.28 13.97 30-day Min (sec) 556.80 559.74 396.51 94.22 88.28 13.97 Mean (sec) 902.93 902.93 904.05 891.23 891.21 893.26 Total Duration(sec) 298659.48 29874.08 291900.30 130491.69 129208.22 131820.52 Avg. Daily Contact Time (sec) 9955.32 9958.14 9730.01 439.72 4306.93 4334.02 Avg. Contact Time (min) 165.92 165.97 162.17 72.50 717.8 73.23 Avg. Contact Duration (min) 12.48 12.48 12.22 11.69 11.64 11.56 Contact Duration (min) 12.48 12.22 11.69 11.64 11.56 Contact Duration (min) 12.48 12.22 11.69 11.64 11.56 Contact Duration (min) 12.48 12.22 11.69 11.64 11.56 Contact Duration (Contact Duration (min)	┙	7.57	7.45	7.81	7.78	7.68	7.28	7.62	7.67	7.39	7.37	7.42	7.26	7.29	7.24
30-day Min (sec) 556.80 559.74 396.51 94.22 88.28 13.87 Max (sec) 962.90 904.05 891.23 891.21 892.26 13.97 Mean (sec) 962.90 904.05 891.23 891.21 893.26 893.79 Total Duration(sec) 29865.948 298744.08 291900.30 130491.69 129208.32 131820.52 Avg. Dally Contact Time (min) 4977.66 4979.07 4865.01 2174.86 2153.47 2197.01 Avg. Contact Time (min) 165.92 165.97 162.17 72.50 71.78 73.23 Avg. Contact Duration (sec) 748.52 748.73 733.42 701.57 698.42 693.79 Contact Duration (sec) 748.52 748.73 733.42 701.57 698.42 693.79 Contact Duration (min) 12.48 12.22 11.69 11.64 11.56 Constellation Contact 494.10 222.71 48.97 68.94 78.40	1		Constellation Contact		190.46			92.83		+	67.99		1	59.42			59.27	
Max (sec) 556.80 559.74 336.51 99.22 88.28 13.87 Max (sec) 902.93 902.96 904.05 891.23 891.21 893.26 Mean (sec) 748.52 748.73 733.42 701.57 698.29 13.87 Total Duration (min) 4977.66 4979.07 4865.01 2174.86 2153.47 2197.01 Avg. Dally Contact Time (min) 165.92 165.97 162.17 72.50 71.78 73.23 Contact Duration (sec) 9955.32 9958.14 9730.01 4349.72 4306.94 4394.02 Avg. Contact Duration (sec) 748.52 748.73 733.42 701.57 698.42 693.79 Contact Duration (min) 12.48 12.48 12.22 11.69 11.64 11.56 Constellation Contact 1003.14 1000.466 929.71 48.97 68.94 78.40 Avg. Contact Duration (sec) 748.52 748.73 733.42 701.57 698.42 693.79 Constellation Contact 494.10 12.22 11.69 11.64 11.56 Avg. Contact Duration (sec) 1003.14 1000.466 929.71 48.97 68.94 78.40					1				1							1		1
Avg. Daily Contact Direction (min) 12.48 29.71 30.23 30.25 <th< td=""><th>305</th><td>30-day</td><td>Min (sec)</td><td>256.80</td><td>929.74</td><td>396.51</td><td>94.22</td><td>97.89</td><td>13.97</td><td>07 (67</td><td>80.48</td><td>92.90</td><td>102.44</td><td>24.8/</td><td>150.40</td><td>63.42</td><td>19.23</td><td>01.8/</td></th<>	305	30-day	Min (sec)	256.80	929.74	396.51	94.22	97.89	13.97	07 (67	80.48	92.90	102.44	24.8/	150.40	63.42	19.23	01.8/
Avg. Daily Contact Time (sec) 296659.48 298744.08 281900.30 130491.69 129206.32 131820.52 170481 Duration (min) 4977.66 4979.07 4865.01 2174.86 2153.47 2197.01 Avg. Daily Contact Time (min) 165.92 165.97 162.17 72.50 71.78 73.23 Avg. Contact Duration (sec) 748.52 748.73 733.42 701.57 698.42 693.79 Contact Duration (min) 12.48 12.48 12.22 11.69 11.64 11.56 Constellation Contact Duration (min) 12.48 12.22 11.69 11.69 11.64 11.56 30-48v Min (sec) 1003.14 1004.66 92.71 48.97 68.94 78.40	F		Mean (sec)	748.52	748 73	733.42	701.57	698 42	693 79	692 41	696 93	688.37	675.08	668 62	676.86	661 14	663.35	652 43
Avg. Daily Contact Time (sec) 9955.32 9958.14 973.01 4349.72 4394.02 197.01 Avg. Contact Time (min) 165.92 165.97 162.17 72.50 71.78 73.33 Avg. Contact Duration (sec) 748.52 748.73 733.42 701.57 698.42 698.49 Contact Duration (min) 12.48 12.22 11.69 11.64 11.56 Constellation Contact 1003.14 1004.66 929.71 48.97 68.94 78.40			Total Duration(sec)	298659.48	298744.08	291900.30	130491.69	_	131820.52	93475.37	93388.60	94994.54	82359.99	٣	81900.17	81320.22	80928.95	81553.88
Avg. Dally Contact Time (sec) 9955.32 9958.14 9730.01 4349.72 4306.34 4394.02 Contact Time (min) 165.92 165.97 162.17 72.50 71.78 73.23 Avg. Contact Duration (sec) 748.52 748.73 733.42 701.57 698.42 693.79 Contact Duration (min) 12.48 12.22 11.69 11.64 11.56 Constellation Contact 494.10 494.10 217.51 48.97 68.94 78.40			Total Duration (min)	4977.66	4979.07	4865.01	2174.86	_	2197.01	1557.92	-	1583.24	1372.67	╌	1365.00	1355.34	1348.82	1359.23
Avg. Daily Contact Time (sec) 9955.32 9958.14 9730.01 4349.72 4306.94 4394.02 Contact Time (min) 165.92 165.97 162.17 72.50 71.76 73.23 Avg. Contact Duration (sec) 748.52 748.73 733.42 701.57 698.42 693.79 Contact Duration (min) 12.48 12.22 11.69 11.64 11.56 Constellation Contact 494.10 494.10 217.51 48.97 68.94 78.40																		
Contact Time (min) 165 92 165 97 162 17 72.50 71.78 73.23 Avg. Contact Duration (min) 13.30 13.37 6.20 6.17 6.33 Contact Duration (min) 12.48 12.48 12.22 11.69 11.64 11.56 Constellation Contact 494.10 494.10 494.10 48.97 68.94 78.40	. 1	Avg. Daily		9955.32	9958.14	9730.01	4349.72	4306.94	4394.02	3115.85	3112.95	3166.48	2745.33	2696.78	2730.01	2710.67	2697.63	2718.46
Avg. Contact Duration (sec) 748.52 748.73 733.42 6.20 6.17 6.33 Contact Duration (min) 12.48 12.48 12.22 11.69 11.64 11.56 Constellation Contact 494.10 494.10 217.51 217.51 217.51 30-day Min (sec) 1003.14 1004.66 929.71 48.97 68.94 78.40				165.92	165.97	162.17	72.50	71.78	73.23	51.93	51.88	52.77	45.76	44.95	45.50	45.18	44.96	45.31
Avg. Contact Duration (sec) 748.52 748.73 733.42 701.57 698.42 693.79 Contact Duration (min) 12.48 12.22 11.69 11.64 11.56 Constellation Contact 494.10 217.51 30-dav Min (sec) 1003.14 1004.66 929.71 48.97 68.94 78.40			Number of Contacts	13.30	13.30	13.27	6.20	6.17	6.33	4.50	4.47	4.60	4.07	4.03	4.03	4.10	4.07	4.17
Contact Duration (min) 12.48 12.22 11.69 11.64 11.56 Constellation Contact 494.10 217.51 30-day Min (sec) 1003.14 1004.66 929.71 48.97 68.94 78.40			Contact Duration (sec)	\sqcup	748.73	733.42	701.57	698.42	693.79	692.41	696.93	688.37	675.08	668.62	98.929	661.14	663.35	652.43
Constellation Contact 494.10 217.51 30-day Min (sec) 1003.14 1004.66 929.71 48.97 68.94 78.40			Contact Duration (min)		12.48	12.22	11.69	11.64	11.56	11.54	11.62	11 47	11.25	11,14	11.28	11.02	11.06	10.87
30-dav Min (sec) 1003.14 1004.66 929.71 48.97 68.94 78.40			Constellation Contact		494.10			217.51			156.63			136.16			135.52	
30-day Min (sec) 1003,14 1004,66 929,71 48,97 68,94 78,40	1					-												
	40°	30-day	Min (sec)	1003,14	1004 66		48.97	68.94	78.40	64.04	143.91	141.51	197.29	117.35	70.28	112.96	298.47	79.42

	Max (sec)	1212.16	1212.23 1213.66	1213.66	1196.55	1196.50	1199.25	1172 96	1173 16	1176.65	1145 9R	1145 BB	1149 11	1118 16	1118 00	1110 07
	Mean (sec)	1115.25	1115.25 1115.39	1107.63	923 63	922 15	923.75	925.23	938.09	932 14	014 65	015.60	016.46	000 74	200	0.00
	Total Duration(sac)	444983 97 445041 28 440835 75	445041 28	440836 75	SC SANBAC	247024 90	253106 10	470242 40	20,000	200000	0.516	20.016	213.43	000 / 1	60 660	200.00
	(555) (515) (515)			2	240430.60	240400 20 24/32/00 23/00/13	533100.13	1/0242 40	10242 40 1716/1.10	174303.60	149087.75	149087.75 147423.95	148302.57	147526.43	47526 43 147582 44	147944.00
	Total Duration (min)	7416.40 7417.35 7347.28	7417.35	7347.28	4140.94	4132.03	4218.44	2837.37	2861.19	2905.16	2484.80	2457.07	2471.71	2458 77	2459 71	2465 73
_																
Avg. Dally	Avg. Dally Contact Time (sec)	14832 80	14834 71 14694 56	14694 56	8281 BB	8264 OG	8436.87	27 7 7 2 2	700073	5840.33	1000	3,7,70	9,00		1	
						27.00	20.00	2	3166.31	26.0160	4505.05	4914.13	4343.42	491/35	49.3.41	4931.47
	Contact Time (min)	247.21	247.25	244.91	138.03	137.73	140.61	94.58	95.37	96.84	82.83	81.90	82.39	81.96	81.99	82 19
	Number of Contacts	13.30	13.30	13.27	8.97	8.97	9.13	6.13	6.10	6.23	5.43	5.37	5.40	5 43	5.47	5,60
Avg.	Contact Duration (sec)	1115.25	1115.39	1107.63	923.63	921.64	923.75	925.23	938 09	932 14	914.65	915.6B	915.45	7, 888	90 90	280.63
	Contact Duration (min)	18.59	18.59	18.46	15.39	15.36	15.40	15.42	15.63	15.54	15.24	15.26	15.26	14.81	503	14 68
	Constellation Contact		739.43		_	416.43			286.60			25.55				

					Table 5.	MEAN MOTION CALCULATED FROM 1000 KM = 13.69872239 REVS/DAY	CALCULAT	ED FROM 100	0 KM = 13.690	3/2239 REVS	3/DAY						
				Ц	1 1												
			INCLINATION	7													
			20°			40°			.09			80°			100		
Half Angle 10°	10°		TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE	TORS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE
	30-day	lay Min (sec)	37.05	20.28	24.32	57.41	50.78	12.44	96.99	99.08	10.66	28.17	36.53	44.74	62.53	30.81	26.61
		Max (sec)	310.35	310.32	310.57	305.96	305.62	306.63	299.75	299.76	300.71	292.51	292.47	449.00	344.61	284.78	284.63
		Mean (sec)	244.86	241.44	235.71	238.61	236.49	240.27	240.81	244.18	229.83	219.55	229.15	237.05	223.03	229.00	220.33
		Total Duration(sec)	c) 25465.82	25592.88	25928.55	13839.30	13952.78	12974.73	9632.50	10011.38	9882.51	8782.09	8478.70	9007.82	8698.10	8472.84	8813.27
		Total Duration (min)	n) 424.43	426.55	432.14	230.66	232.55	216.25	160.54	166.86	164.71	146.37	141.31	150.13	144.97	141.21	146.89
	Avg. Daily	Daily Contact Time (sec)	3 848.86	853.10	864.29	461.31	465.09	432.49	321.08	333.71	329.42	292.74	282.62	300.26	289.94	282.43	293.78
		Contact Time (min)	14.15	14.22	14.40	7.69	7.75	7.21	5.35	5.56	5.49	4.88	4.71	5.00	4.83	4.71	4.90
		Number of Contacts	1s 3.47	3.53	3.67	1.93	1.97	1.80	1.33	1.37	1.43	1.33	1.23	1.27	1.30	1.23	1.33
	Avg.	g. Contact Duration (sec)	ec) 244.86	241.44	235.71	238.61	236.49	240.27	240.81	244.18	229.83	219.55	229.15	237.05	223.03	229.00	220.33
		Contact Duration (min)	nin) 4.08	4.02	3.93	3.98	3.94	4.00	4.01	4.07	3.83	3.66	3.82	3.95	3.72	3.82	3.67
		Constellation Contact	act	42.78			22.65			16.39			14.58			14.41	
	20° 30-day	lay Min (sec)	46.61	31.51	27.52	66.20	70.31	41.83	60.58	25.72	96.44	12.24	46.06	22.83	63.63	91.92	88.05
		Max (sec)	622.64	622.64	623.33	614.01	613.75	615.40	601.47	601.40	603.37	586.88	586.77	588.18	571.98	571.90	571.72
		Mean (sec)	470.32	467.80	462.94	479.19	471.98	490.86	470.83	477.86	476.29	452.02	455.31	462.12	452.69	448.36	450.57
		Total Duration(sec)	c) 113346.00	113207.12	115273.28	54627.68	55222.00	55467.71	40020.90	40140.14	40960.58	35709.24	35058.80	35120.99	34857.14	34971.99	35595.29
		Total Duration (min.)	n) 1889.10	1886.79	1921.22	910.46	920.37	924.46	667.02	669.00	682.68	595.15	584.31	585.35	580.95	582.87	593.25
	Avg. Daily	Daily Contact Time (sec)	3778.20	3773.57	3842.44	1820.92	1840.73	1848.92	1334.03	1338.00	1365.35	1190.31	1168.63	1170.70	1161.90	1165.73	1186.51
		Contact Time (min)	η 62.97	65.89	64.04	30.35	30.68	30.82	22.23	22.30	22.76	19.84	19.48	19.51	19.37	19.43	19.78
	-	Number of Contacts	ts 8.03	8.07	8.30	3.80	3.90	3.77	2.83	2.80	2.87	2.63	2.57	2.53	2.57	2.60	2.63
	Avg.	╗	Ĭ	467.80	462.94	479.19	471.98	490.86	470.83	477.86	476.29	452.02	455.31	462.12	452.69	448.36	450.57
	-	Contact Duration (min)	nin) 7.84	7.80	7.72	7.99	7.87	8.18	7.85	7.96	7.94	7.53	7.59	7.70	7.54	7.47	7.51
		Constellation Contact	act	189.90			91.87			67.29			58.80			58.57	
	1																
	30° 30-day	4	573.77	393.31	157.90	44.26	96.39	16.01	51.81	89.01	89.46	38.08	91.06	112.06	145.40	52.07	74.18
	+	Max (sec)	938.78	938.78	939.84	925.86	925.58	927.98	66.906	\dashv	909.75	884.98	884.81	887.31	862.58	862.43	862.64
	\dashv	Mean (sec)	776.84	775.15	769.54	716.57	718.24		718.00	719.49	720.61	692.80	693.14	698.35	688.26	670.95	682.70
	-	Total Duration(sec)	c) 295976.87	296108.38	293965.05	128982.76	128982.76 129284.10	131754.68	91904.70	92814.13	94399.38	81751.00	80403 81	80309.98	80526.19	79843.56	80558.41
		Total Duration (min)	n) 4932.95	4935.14	4899.42	2149.71	2154.73	2195.91	1531.74	1546.90	1573.32	1362.52	1340.06	1338,50	1342.10	1330.73	1342.64
	Avg. daily	daily Contact Time (sec)	9865.90	9870.28	9798.83	4299.43	4309.47	4391.82	3063.49	3093.80	3146.65	2725.03	2680.13	2677.00	2684.21	2661.45	2685.28
	-	Contact Time (min)	164.43	164.50	163.31	71.66	71.82	73.20	51.06	51.56	52.44	45.42	44.67	44.62	44.74	44.36	44.75
	-	Number of Contacts	ts 12.70	12.73	12.73	00:9	9.00	6.23	4.27	4.30	4.37	3.93	3.87	3.83	3.90	3.97	3.93
	Avg.	g. Contact Duration (sec)	ec) 776.84	775.15	769.54	716.57	718.24	704.57	718.01	719.49	720.61	692.81	693.14	698.35	688.26	670.95	682.70
	-	Contact Duration (min)	in) 12.95	12.92	12.83	11.94	11.97	11.74	11.97	11.99	12.01	11.55	11.55	11.64	11.47	11.18	11.38
	-	Constellation Contact	3ct	492 16			216.64			155.15			134.66			133.85	
	_1.	4							1]					
	40° 30-day	ay Min (sec)	1041.64	559.74	429.30	78.34	58.00	67.33	83.68	140.92	57.94	173.55	221.24	270.75	121 13	254.53	137.68

		-														
	Max (sec)	1260.52	1260.54	1261.99	1243.29	1242.96	1246.22	1218.03	1217.79	1221.75	1188.44	1188.21	1191.73	1158.40	1158.27	1158.67
	Mean (sec)	1159.01	1159.01 1157.04	1154.75	965.88	972 74	952.09	967.82	972.29	966.33	950.57	953.22	957.38	916.39	932.47	926.35
	Total Duration(sec)	441583.57 441989.34 441112.91	441989.34	441112.91	244368.9	244368 98 244158 30 254208 94	254208.94	168401.61	170151.54	172972.55	147338.08	47338.08 145842.54	146479.05	145705.49 145464.84	145464.84	146363.31
	Total Duration (min)	7359.73	7366.49	7351.88	4072.82	4069.31	4236.82	2806.69	2835.86	2882.88	2455.63	2430.71	2441.32	2428.42	2424.41	2439.39
Avg. Dail	Avg. Daily Contact Time (sec)	14719.45	14732.98	14703.76	8145.63	8138.61	8473.63	5613.39	5671.72	5765.75	4911.27	4861.42	4882.64	4856.85	4848.83	4878.78
	Contact Time (min)	245.32	245.55	245.06	135.76	135.64	141.23	93.56	94.53	96.10	81.85	81.02	81.38	80.95	1808	81.31
	Number of Contacts	12.70	12.73	12.73	8.43	8.37	8.90	5.80	5.83	5.97	5.17	5.10	5.10	5.30	5.20	5.27
Avg.	Avg. Contact Duration (sec)	1159.01	1157.04	1154.75	965.89	972.74	952.09	967.83	972.29	966.33	950.57	953.22	957.38	916.39	932.47	926.35
	Contact Duration (min)	19.32	19.28	19.25	16.10	16.21	15.87	16.13	16.20	16.11	15.84	15.89	15.96	15.27	15.54	15.44
	Constellation Contact		735.81			412.63			284 18			244.31	-		243 13	

	-																
	-		INCLINATION														
	H		20°			40.			.09			.08			100		
Half Angle 10°	10°		TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE	TORS-E	TDRS-W 1	TDRS-ZOE
	30-	30-day Min (sec)	17.88	39.54	26.03	173.33	273.75	53.10	34.58	69.63	36.81	66.44	46.65	53.54	110.58	51.94	21.32
	_	Max (sec)	322.18	408.67	322.58	436.79	317.52	307.89	310.64	310.66	382.19	302.62	302.76	303.59	294.20	294.84	294.63
		Mean (sec)	251.92	257.09	248.75	270.48	305.85	236.81	242.38	258.92	219.11	227.73	233.71	240.98	236.65	226.58	227.09
		Total Duration(sec)	(sec) 25443.67	24937.86	26118.39	16228.90	0 18656.54	12551.06	11149.44	11651.23	7887.94	7287.24	8179.93	9880.24	8046.24	8156.89	9310.85
		Total Duration (min)	(min) 424.06	415.63	435.31	270.48	310.94	209.18	185.82	194.19	131.47	121.45	136.33	164.67	134.10	135.95	155.18
	Avg	Avg. Daily Contact Time (sec)	(sec) 848.12	831.26	870.61	540.96	621.88	418.37	371.65	388.37	262.93	242.91	272.66	329.34	268.21	271.90	310.36
		Contact Time (min)	(min) 14.14	13.85	14.51	9.02	10.36	6.97	6.19	6.47	4.38	4.05	4.54	5.49	4.47	4.53	5.17
		Number of Contacts	lacts 3.37	3.23	3.50	2.00	2.03	1.77	1.53	1.50	1.20	1.07	1.17	1.37	1.13	1.20	1.37
	Ą	Avg. Contact Duration (sec)	n (sec) 251.92	257.09	248.75	270.48	305.85	236.81	242.38	258.92	219.11	227.73	233.71	240.98	236.65	226.58	227.09
		Contact Duration (min)	1 (min) 4.20	4.28	4.15	4.51	5.10	3.95	4.04	4.32	3.65	3.80	3.90	4.02	3.94	3.78	3.78
		Constellation Contact	ontact	42.50			26.35			17.04			14.12			14.17	
]												
. •	20° 30.	30-day Min (sec)	46.44	30.28	53.12	82.34	46.90	83.10	73.00	56.11	45.91	116.38	111.71	124.85	174.90	9.70	94.72
		Max (sec)	646.44	646.38	647.26	635.92	637.08	631.89	623.47	623.36	620.39	607.57	607.55	16.609	591.27	591.67	591.68
		Mean (sec)	489.16	489.03	487.84	478.23	495.77	498.28	514.89	513.65	468.91	466.58	474.66	499.25	464.84	457.68	475.11
		Total Duration(sec)	(sec) 112017.22	111498.22	119034.19	52605.12	2 43627.84	58298.46	38616.55	39551.15	41264.04	34993.47	34650.14	34947.35	34862.96	34783.82	35158 20
	4	Total Duration (min.)	\dashv	1858.30	1983.90	876.75	727.13	971.64	643.61	659 19	687.73	583.22	577.50	582.46	581.05	579.73	585.97
	Avg.	Avg. Daily Contact Time (sec)	(sec) 3733.91	3716.61	3967.81	1753.50	1454.26	1943.28	1287.22	1318.37	1375.47	1166.45	1155.00	1164.91	1162.10	1159.46	1171.94
	+	Contact Time (min)	(min) 62.23	61.94	66.13	29.23	24.24	32.39	21.45	21.97	22.92	19.44	19.25	19.42	19.37	19.32	19.53
	$\frac{1}{2}$	Number of Contacts	\perp	7.60	8.13	3.67	\dashv	3.90	2.50	2.57	2.93	2.50	2.43	2.33	2.50	2.53	2.47
	Avg	П		489.03	487.85	478.23	495.77	498.28	514.89	513.65	468.91	466.58	474.66	499.25	464.84	457.68	475.11
	\dashv	Contact Duration (min)	1 (min.) 8.15	8.15	8.13	7.97	8.26	8.30	8.58	8.56	7.82	7.78	7.91	8.32	7.75	7.63	7.92
	\dashv	Constellation Contact	ontact	190.25		_	85.85			66.35			58.05			58.23	
							+									1	
	30°	30-day Min (sec)	1	529.94	442.17	139.66	+	99.99	101.31	77.37	274.00	108.74	123.11	119.64	250.01	153.05	120.30
	$\frac{1}{1}$	Max (sec)	+	974.72	976.04	00 096	+	956.83	940.26	940 14	939.76	916.36	916.25	919.03	892.04	892.30	892.57
	$\frac{1}{1}$	Mean (sec)	+	803.02	810.14	725.09	_	728.13	737.54	726.60	789.51	731.28	726.02	724.91	715.45	710.48	699.18
	+	Total Duration(sec)	7	293906.98	295700.25	131966.13	듸	131063.85	89980.53	90098.81	95530.84	82635.15	79861.92	77565.69	80130.76	80284.55	79006.91
	+	Total Duration (min)	(min) 4897.88	4898.45	4928.34	2199.44	2296.19	2184.40	1499.68	1501.65	1592.18	1377.25	1331.03	1292.76	1335.51	1338.08	1316.78
	+		+			$\frac{1}{1}$	+										
	Avg.	Avg. Daily Contact Time (sec)	4	9796.90	9856.67	4398.87	4592.38	4368.79	2999.35	3003.29	3184.36	2754.50	2662.06	2585.52	2671.03	2676.15	2633.56
		Contact Time (min)	(min) 163.26	163.28	164.28	73.31	76.54	72.81	49.99	50.05	53.07	45.91	44.37	43.09	44.52	44.60	43.89
	-	Number of Contacts	┙	12.20	12.17	6.07	6.10	0.00	4.07	4.13	4.03	3.77	3.67	3.57	3.73	3.77	3.77
	₹ 	Avg. Contact Duration (sec)	n (sec) 805.13	803.02	810.14	725.09	752.85	728.13	737.55	726.60	789.51	731.28	726.02	724.91	715.45	710.48	699.18
	4	Contact Duration (min)	13.42 (min)	13.38	13.50	12.08	12.55	12.14	12.29	12.11	13.16	12.19	12.10	12.08	11.92	11.84	11.65
		Constellation Contact	ontact	490.91	1		222.71			153.07			133.49			133.05	
		4	1														
	40° 30-6	30-day Min (sec)	1	706.88	1010.35	262.18	-+	242 61	204.30	_	154.86	83.14	124.12	83.91	115.57	98.22	195.57
	$\frac{1}{2}$	Max (sec)	1309.19	1309.10	1310.86	1289.99	1290.38	1287.23	1263.00	1262.81	1264.28	1230.96	1230.77	1234.54	1198.46	1198.58	1199.04

		240 79			241 38			282.49			402.87		 	732 84		Constellation Contact		_	
	15.71	15.96	15.87	16.06	16.42	16.77	16.66	16.80	16.65	17.24	16.06	16.57	20.11	20.01	20.05	Contact Duration (min)		\dashv	
	942.40	257.37	951.98	963.51	985.13	1006.38	999.72	1007.96	999.25	1034.60	963.60	994.37	1206.68	1200.34	1203.05	Avg. Contact Duration (sec)	Avg.	-	
_	5.17	9.00	5.03	5.07	4.87	4.77	5.57	2.67	5.67	8.10	8.03	8.10	12.17	12.20	12.17	Number of Contacts		\dashv	
_	81.15	82.62	29.86	81.36	29.90	79.95	92.75	95.20	94.37	139.67	129.02	134.24	244.69	244.07	243.95	Contact Time (min)		\dashv	لـــ
_	4869.04	4786.86	4791.62	4881.81	4794.28	4797.08	5565.09	5711.76	5662.43	8380.27	7740.92	8054.41	14681.25	14644.17 14681.25	14637.11	Avg. Daily Contact Time (sec)	Avg. Daily	Н	Ш
_																		Н	
_	2434.52	2393.43	2395.81	2440.90	2397.14	2398.54	2782.54	2855.88	2831.21	4190.14	3870.46	4027.21	7340.62	7322.08	7318.55	Total Duration (min)		Н	
_	146071.31	143748.66 143605.75	143748.66	146454.20	143828.54	143912.28	171352.79 166952.67		169872.80	1408 14	241632 43 232227 62 251408 14	241632.43 2	440437.38	439325.09 440437.38	439113.20	Total Duration(sec)		Н	
	942.40	957.37	951.98	963.51	985.13	1006.38	999.72	1007.96	999.25	1034.60	963.60	994.37	1206.68	1200.34	1203.05	Mean (sec)		Ц	

Figure 4. Average Number of Contacts per Day as a Function of Orbital Altitude, Orbital Inclination Angle, and Antenna

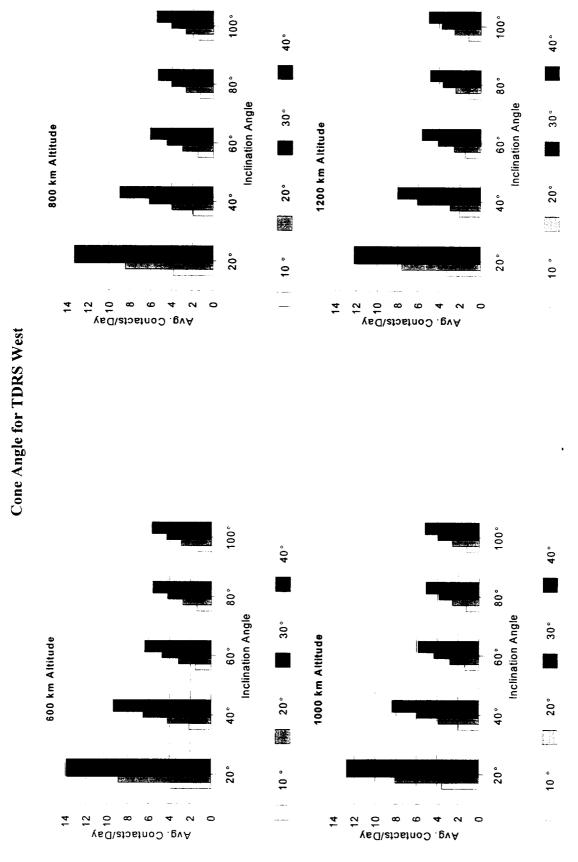


Figure 5. Average Contact Duration as a Function of Orbital Altitude, Orbital Inclination Angle, and Antenna Cone Angle for

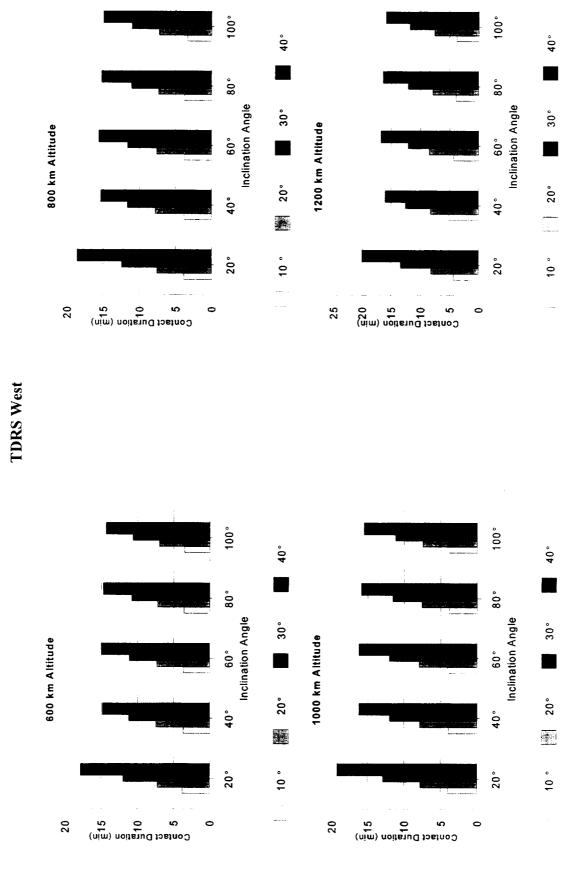
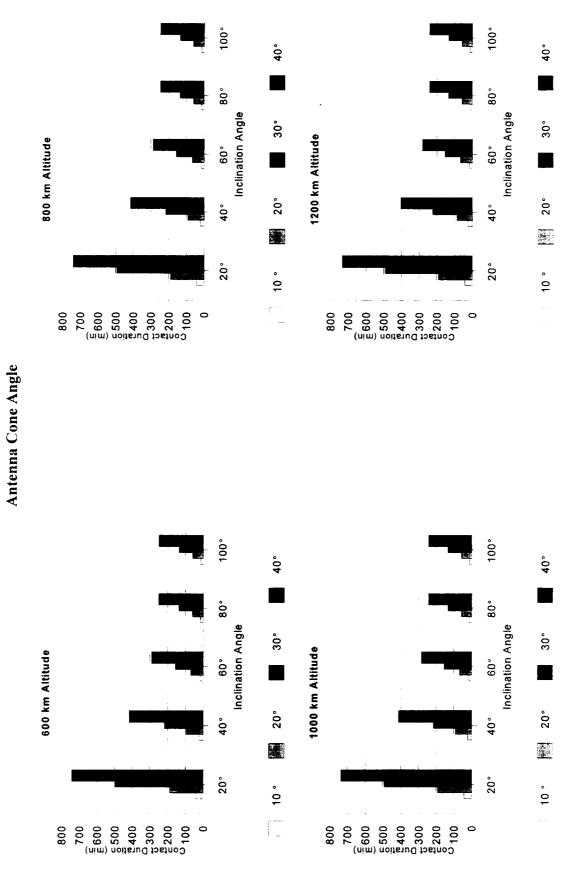


Figure 6. Total Constellation Average Contact Time as a Function of Orbital Altitude, Orbital Inclination Angle, and



SECTION 5 - CONCLUSIONS AND FURTHER WORK

Based on this improved study of the access times of a non-gimbaled antenna on a spinning satellite, we conclude that the basic technique previously described holds up when the simulation duration is extended to 30 days. In particular,

- a. the improved simulation methodology with more accurate orbital element propagation techniques shows that the basic simulation methodology used in the original analysis was basically correct and the conclusions drawn from those initial studies were on the right track.
- b. the non-gimbaled antenna pointing shows that at least 3 contacts per day are possible with existing technology and up to 15 contacts per day are possible with the correct choice of antenna and orbital inclination,
- the antenna needed for the higher numbers of contacts per day is possible with current technology; for example, S-Band microstrip antennas with HPBW of 80° (40° cone angle) and gains of 5 dB, or microstrip arrays with HPBW of 40° (20° cone angle) and gains of 8 dB are available at NMSU and would be applicable to this mode of communication.
- d. the non-gimbaled antenna pointing gives sufficient contact time through the entire Space Network constellation to make this communication mode reasonable to investigate for actual usage since the technique provides approximately 15 minutes per day at the low end up through several hundred minutes at the high end with the duration being a function of the orbital inclination and antenna HPBW,
- e. the third TDRS covering the ZOE enhances the contact availability and total time per day for contacts.

Naturally, the exact amount of time available to a user will also be a function of the current network loading and mission operations needs.

The next step in this study is to apply these results to the improved TDRS link margins to compute the expected data throughput for the system. Since the improved TDRS link margins allow for lower signal levels, it is expected that these results will better show that this potential

access method is viable for small satellites. This work will be presented in a subsequent technical report in this series.

SECTION 6 - REFERENCES

- [1] S. Horan, W. P. Osborne, and T. Minnix, "Improved Small Satellite Access of the Space Network," NMSU-ECE-94-014, December 14, 1994.
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- [3] S. Horan, "Small Satellite Access of the Space Network," *Proc. Space Technology and Applications International Forum*, Albuquerque, NM, January 1996, p. 501-506.
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Appendix - Acronym List

HPBW Half Power Beam Width

LEO Low Earth Orbit

MA Mean Anomaly

MM Mean Motion

NASA National Aeronautics and Space Administration

RAAN Right Ascension of the Ascending Node

SN Space Network

STK Satellite Tool Kit

TDRS Tracking and Data Relay Satellite

TDRS-E TDRS - East

TDRS-W TDRS - West

TDRS-ZOE TDRS - Zone of Exclusion

ZOE Zone of Exclusion

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